THE IMPROVEMENT OF DIVERS' COMPENSATION FOR UNDERWATER DISTORTIONS

by

Jo Ann S. Kinney, Ph.D.
Christine L. McKay, M.A.
S.M. Luria, Ph.D.
and
Colleen L. Gratto

SUBMARINE MEDICAL RESEARCH LABORATORY
NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 633

Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4306.03-2050D.02

Reviewed and Approved by:

Charles F. Gell

Charles F. Gell, M.D., D.Sc. (Med)
Scientific Director
SubMedResLab

Reviewed and Approved by:

Joseph D Bloom.

J. D. Bloom, CDR, MC, USN
Officer-in-Charge
SubMedResLab

Approved and Released by:

J E Stark

J. E. Stark, CAPT MC USN
COMMANDING OFFICER
Naval Submarine Medical Center

SUMMARY PAGE

THE PROBLEM

To determine which underwater activities lead to the greatest adjustment, or adaptation, for SCUBA divers to the underwater distortions.

FINDINGS

The results of several related studies have shown that training on a specific task of hand-eye coordination transfers to other visual-motor skills under water; that a small amount of underwater adjustment is achieved rapidly and quickly--within a few minutes; and that amounts large enough to be meaningful for diver efficiency under water are much more difficult to obtain but that certain activities do facilitate this process.

APPLICATION

The results are applicable to the training of NAVY SCUBA divers. Training procedures can be based upon these results which should reduce the time required for adequate underwater adjustment by a considerable amount.

ADMINISTRATIVE INFORMATION

The investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit M4306.03-2050D, Evaluation of Sensory Aids and Training Procedures on Underwater Visual Efficiency. The present report is No. 2 on that Work Unit. It was approved for publication on 25 June 1970 and designated as Submarine Medical Research Laboratory Report No. 633.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL CENTER

ABSTRACT

A series of experiments was undertaken to develop techniques for facilitating a diver's adjustments to underwater activities. The results show clearly that such facilitation is possible, but that complete adjustment is not obtained easily or automatically. Nonetheless, a technique was devised which does expedite the normally long time periods required; it consists of performing tasks under water on a spaced schedule. The success of the technique is attested to by the fact that more adaptation was achieved by a group, on this schedule, in 15 minutes of underwater activity than by a class of SCUBA divers in four weeks.

THE IMPROVEMENT OF DIVERS' COMPENSATION FOR UNDERWATER DISTORTION

GENERAL OVERVIEW OF STUDIES REPORTED

The Problem

Transmission of light through water seriously distorts the optical image and consequently disrupts visually guided behavior and the ability to judge size and distance under water. Novice divers are particularly plagued by finding that objects are not located in the undersea world at the position at which they appear. Some highly experienced divers, on the other hand, show the ideal response of complete adaptation; that is, they react with reference to the physical location of objects rather than to the optical image.[1] This response occurs immediately upon entering the water, and appears to be a completely unconscious reaction derived, no doubt, from hundreds of hours of underwater experience doing all types of activities. In fact, we have found an excellent correlation between test results of hand-eye coordination under water and underwater competence or proficiency ratings of divers.

In a previous investigation we attempted to trace the development of this adaptive response in a class of new SCUBA divers.[1] The men were given a battery of tests, including size perception, distance perception, and visual-motor skills, weekly, during the course of their SCUBA training. The aim was to trace the development of the various skills as the men gained proficiency in dealing with underwater distortion. The data revealed that the men in the classes obtained some degree of adaptation during the course, but the amount was surprisingly small. Even after four weeks of intensive daily underwater work, the divers on the average showed adaptation amounting to only 20 percent.

Thus, it would appear that there is tremendous room for improvement in hand-eye coordination in beginning divers and that specific training or specifically designed activities could easily be added to the curriculum of SCUBA divers to facilitate this improvement.

A major aim of our research is to determine which underwater activities lead to the greatest amount of generalized adaptation and to specify means of improving diving training in this area.

Related Investigations in Air

There is a phenomenon studied in air--adaptation to distorted stimulation--that is essentially the same problem faced by individuals under water. The first investigator, Stratton in 1896,[2] was bothered by the lack of isomorphism between physical space and the inverted retinal image produced by the lens in the human eye; he wore inverting prisms in front of his eyes for a period of eight days in order to see if he could adjust to the artificially-produced, upright image. He found that, while initially the entire scene looked upside down and swung before his eyes, after several days he

gradually began to respond appropriately and could move about in his environment without confusion or collisions.

Later investigators became interested in the technique of distorting the normal stimulation in an attempt to understand the perceptual process in general.[3,4,5] The results clearly uphold the original descriptions of Stratton: when human beings are faced with a discordance between their normal visual-motor responses and the current stimulation, the old habits will eventually break down and be replaced by new responses appropriate to the novel stimulation. This ability to adjust or adapt to the new situation varies phylogenetically; only mammals appear capable of the adjustment; also, greater amounts of adaptation are possible among the higher than in the lower mammals.[6]

Because of the importance of the phenomenon of adaptation to distorted stimulation to a general understanding of perception, extensive investigations have been performed in recent years. Less severe distortion and precise measurement of responses, rather than subjective descriptions, are characteristic of the newer work; there is thus a vast body of data on which to draw that should be pertinent to the study of underwater distortions.[7,8,9]

Methodology

Adaptation experiments performed in air have followed a widely used experimental paradigm, that of the pre- and post-tests. Subjects are measured on a specific device in their normal environment; some sort of distortion of this environment is then introduced for a given period of time; finally the distortion is removed and the subjects retested normally. If the distortion is visual, objects will not be located physically where they appear optically, and visual-motor behavior will at first be inappropriate. Gradually subjects will learn to respond to the appropriate physical location and will continue to do so for a short time after the distortion is removed. This after-effect, or response in the opposite direction from the original distortion, is used to estimate the amount of adaptation achieved.

The measure has several advantages; it is, of course, an extremely simple test to administer and to score. Of greater importance is the fact that it eliminates conscious or cognitive control of behavior as an explanation of adaptation. If the subject were consciously correcting for the distortion, there would be no reason to continue to do so after the distortion was removed.

There are, however, at least two major disadvantages. It assumes a perfect correlation between the amount of after-effect measured and the amount of adaptation obtained; this assumption could be invalid for a wide variety of reasons. Furthermore, in the practical situation, we are interested in how the diver performs in the water, not his subsequent behavior in air.

In all of the experiments that follow, therefore, we have measured both the amount of compensation achieved in the water and the amount of the after-effect found in air. This requires at least four measures: the first test in air, another immediately upon entering the

water; a final test in water after an adaptation period, to show the amount of compensation; and a final test in air, to yield the after-effect.

All of the underwater tests took place in an above-ground pool, 20 ft in diameter and four ft deep. Subjects were outfitted with face masks, snorkels, and weight belts. Those with no underwater experience were first instructed with the use of a mask and snorkel before testing.

Testing in air was done outdoors, under natural illumination, in an area near the pool. Subjects also wore the face mask for the tests in air, to eliminate mask-distortions as a possible artifact.

Apparatus

A number of tests were designed to measure various aspects of hand-eye coordination or visual motor behavior in the following studies. Duplicate copies were made of each, one for use in the water and the other in air.

All of the tests involved coordination of some motor response with the location of an object in the subject's environment. The tests can be further categorized into those that allow the subject to view the scene while he is making his response, and those that do not.

Of the former type is a test of hand-eye coordination that we have used extensively in the past.[1,10] Basically it consists of a table with four positions indicated on the top. The subject's task is to mark, on the under side of the table, the positions indicated on top. He is thus not able to see his own hand while marking, but he can see the designated position. The test, referred to hereafter as the Hand-Eye Table, is described in greater detail in Study II and in reference 1; it has proved very reliable in extensive testing over several years and is quite comparable to a device commonly used in air.[11]

In the other type of device, the subject is not allowed to view the physical object while responding to it. Normally, he first looks at some target, his eyes are then shuttered while he makes a designated response toward it, such as reaching or placing. Afterwards he may or may not be allowed to see the results of his response. This type of measure has been advocated by several investigators[8,12] who use the descriptive phrase, "ballistic movement," to describe it. Several devices of this type were employed; in general these ballistic movement tests were not as reliable as those in which visual guidance was allowed.

The same scoring procedure was used whatever test was employed. Measures of the subjects' responses were made in physical units of length. The values in water and the final air value were subtracted from the first measures done in air, to control for individual biases in responding. The first value in water, thus becomes a measure of the original distortion evidenced by the subject; if it is comparable in size to the theoretical optical distortion of the water, he is responding totally on the basis of the optical information. The final water value gives an indication of how much

the subject has adapted; if it is the same as the first water value, he shows no adaptation at all; if it is zero, he has compensated completely. The final air value gives the size of the after-effect; if it is comparable in size to the original distortion evidenced, but opposite in sign, perfect adaptation is assumed.

Summary of Each Study

This report presents the results of four different studies aimed at optimizing the adaptation process for divers; the studies are described briefly below.

(1) Preliminary data on ways to facilitate adaptation under water. Subjects were tested on a visual-motor task involving the perception of depth under water both before and after an adaptation period in the water. For the adaptation period, subjects were assigned to one of seven groups; the tasks performed by some of the groups during the adaptation period were related to the test situation; for others they were not. The major result was that groups which had task-specific experience adapted more than groups with other kinds of underwater experience. Another group, performing a generalized type of underwater activity, also adapted well. Various interpretations of these preliminary data were possible and one, that underwater training might not be transferable, led directly to the second experiment.

(2) The generalization of training in specific hand-eye coordination to other visual motor skills. This is an all-pervasive problem in the development of any training procedures: to be beneficial, the training must be transferable to widely diverse situations. Some major theories hold that adaptation to distorted stimulation is essentially conditioning of motor responses to new types of stimulation.[6, 13, 14] Specificity of training is further suggested by the fact that practice with one hand on a task under distorted conditions generally shows very little transfer to the other hand.[7, 15, 16] This problem could be particularly critical for diver training; if the adaptation process were quite specific to the training, the diver might be unable to cope with novel problems.

This study tested the premise by determining whether training on a specific test of hand-eye coordination, with distorted visual stimuli, transferred to other tests of visual motor skills. Since the study was essentially a control experiment, it was conducted in air; the visual distortion was produced by prisms.

The results showed good transfer of skills achieved in training.

(3) The effectiveness of different underwater activities selected on theoretical grounds. Adaptation to distorted stimulation has been an extremely active field of investigation for psychologists in the past ten years. There are several major theories, all evolved on the basis of extensive research, that purport to explain the underlying mechanisms. While these investigations have been conducted in air, typically using prisms as the distorting device, the theories should apply equally well to the underwater distortions.

Activities for a short period of underwater adaptation were chosen on the basis of the major theories in the field. For example, some individuals actively placed objects at specified, visible positions under water while others passively watched the results of these movements while under water.

The results revealed that all subjects adapted to some extent during the underwater activity period, but the overall amount of adaptation was small--an average of about 20%. Furthermore, there was no difference among the various groups in the amount of adaptation achieved; all groups achieved the same small amount, regardless of whether they performed active visual-motor coordinations under water or simply watched.

These data suggest that a small amount of adaptation under water occurs automatically and very quickly--within two to three minutes. The amount, however, while of interest theoretically, is of no practical importance. To be competent under water, the diver must respond to the true location of objects; he must therefore achieve 100% adaptation or close to that amount. A final experiment was therefore designed in which the adaptation periods were lengthened to 15 minutes in the water and various educational procedures were tested for their effectiveness.

(4) <u>The effectiveness of the scheduling of different underwater activities in producing adaptation.</u> The import of two parameters on adaptation was measured in this study, the type of activity and the scheduling of the exposures.

Active hand-eye coordinations, required to compete in various underwater games, were compared to the effects of a lecture and practice period on underwater distortion and to a control activity, swimming, for the same period of time. Also some groups of subjects were given the 15-minute adaptation period all at one time while other groups received three five-minute underwater intervals separated by activities in the air.

The experiment resulted in meaningful amounts of adaptation for some groups of subjects. Specifically, the group that performed underwater tasks at spaced intervals performed the best, achieving close to 100% adaptation within the 15 minute interval. The control groups who simply swam obtained the least adaptation.

Conclusions

On the basis of the results of these four studies, we have concluded that there are at least two types of adaptation that occur under water.* The first stage is very rapid, small in size and takes place fairly automatically, without special training. Engaging in any activity under water, whether simply swimming around for a few minutes, taking a test of hand-eye coordination under water, or completing a course in SCUBA diving, will result in this adaptation. It is comparable to results in air in which small amounts of adaptation to

**Those interested in the rationale underlying this summary are referred to the General Discussion.*

prisms are achieved in a few minutes. The basis for this type of adaptation is believed to be the different pattern of stimulation across the retina which results from head and eye movements under water as compared with these movements in air. In practical terms, however, the amount of adaptation achieved in this way is not large enough to aid the diver in performing efficiently under water.

The second type is a long term, relatively complete compensation which is much more difficult to achieve. Navy divers, with hundreds of hours of different types of underwater experience, evidence this degree of adjustment. In air, subjects achieve 100% adaptation after days or weeks of distorted stimulation. The mechanism decidely involves new visual-motor coordinations. It is this type of adaptation that we are attempting to facilitate, by short-cutting the normally extensive time-periods required.

Our success to date is attested to by the fact that more adaptation was achieved by a group, using our most effective technique, in 15 minutes of underwater activity than by the class of SCUBA divers in four weeks. The technique, performing tasks under water on a spaced schedule, involves many factors: interest, motivation, scheduling, and active movement of parts of the body in relation to the distorted environment; however, conscious control or informational feedback about errors are not required.

It remains for future research to refine the technique, to determine the minimum amount of time required and whether or not adaptation so achieved is long-lasting.

Study I. Preliminary Data on Ways to Facilitate Adaptation Under Water

Our first study of adaptation to underwater distortions was designed to look at some of the possible techniques for facilitating adaptation that have been suggested by studies in air. A test was designed to measure the subject's visual-motor coordination in depth. After taking the test in air, the subjects were given a five-minute underwater task to promote adaptation, followed by the same test given under water. Proficiency in the test was used as the measure of the effectiveness of the various tasks in promoting adaptation. As a control, one group was given the test immediately upon entering the water without having first done the underwater task. All subjects were also tested in air after leaving the water to measure any after-effect that might have occurred.

Procedure

A ball-dropping task was designed to test visual-motor coordination in depth. Using a 34" rod with a scoop on the end, subjects were asked to drop a one-inch diameter ball-bearing, from a height of 30", into a three-inch diameter cup 42" away. The location of the first ten attempts at the task were

recorded and the subject continued until he successfully dropped the ball in the cup ten times.

Forty subjects, with little or no underwater experience, were first given the test in air and then divided into eight groups, balanced on the basis of their competence on the ball-dropping task. One of the groups served as a control; these subjects were given the ball-dropping test underwater immediately upon entering the water. The other seven groups were given separate underwater tasks, designed to facilitate adaptation, prior to doing the ball-dropping task. Three of the groups performed tasks for five minutes which were related to the ball-dropping test, while the other four groups did unrelated tasks for five minutes. The eight groups are described below:

(1) Control: No underwater activity except taking test.

(2) Passive: Subjects given experience in ball-dropping task without active participation by watching their relaxed arm moved by the experimenter for five minutes of random hits and misses.

(3) Blindfolded: One member of a team who practiced ball-dropping task until ten hits were achieved. This member performed the actual motor manipulations, but was blindfolded so that he could not see the task.

(4) Director: The other member of the team who could see the task and directed the actions of the blindfolded subject by a tapping code on his back.

(5) Pegboard: The underwater activity of this group was unrelated to the ball-dropping task; it consisted of placing pegs in a pegboard. Some of the holes on the pegboard were of appropriate physical size; others were smaller by three quarters, but appeared to be the correct size due to the magnification of the water. The subject was asked to look at the pegboard while feeling the peg and decide which hole appeared appropriate before he attempted to insert it.

(6) Carpentry: Subjects were provided with a hammer, screw driver, nuts, bolts, nails, and screws to attach to a piece of wood under water.

(7) Swim: Subjects swam under water for five minutes using a face mask and snorkel.

(8) Game: A game similar to fencing was designed for underwater play. One member was asked to try to place his short wooden stick through a metal ring held by his opponent, also a member of this group. Each member was given two and one-half minutes holding the stick and ring, respectively.

Results

Figure 1 shows the results for each group averaged over the first nine trials in the underwater ball-dropping test. A positive value indicates the ball landed on the near side of the cup; zero is a direct hit; and negative values mean the ball landed on the far side of the cup. If adaptation had occurred during the five-minute tasks, a horizontal line, with average values of zero inches,

the 2-ft square white table top. The experimenter called out in random order the target locations which the subject was to mark. Each session consisted of two marks at each of the four positions.

Since the subjects could not see their hands while marking, they received no information about their errors during testing. During adaptation, however, the wooden table top was removed and replaced with a clear plexiglass sheet with random target locations painted on the surface. The experimenter again designated which spot was the target, and the subject could now see his hand and guide it to the appropriate location on the underside of the table.

3. Spearing. The subject's task was to touch with a short wooden dowel in his right hand the bulls-eye of a vertical target composed of concentric one-inch circles. The diameter of the target was ten inches in the center of a 17-inch high and 21-inch wide metal sheet. The subject stood at arm's distance from the target, with his left hand holding the upper left corner of the metal sheet. During testing, he was permitted to look at the target, after which is eyes were covered while he attempted to touch the center. Errors were recorded to the nearest .25 inch. The subject received no information about his errors during the six test "spears." Adaptation consisted of approximately the same procedure except that the subject was permitted to look while making the spearing motion.

Results

Table I presents the amount of adaptation obtained for each task as a function of whether or not it was used for the adaptation period. Since there was no difference between the two measures of adaptation (compensation and after-effect), the two were averaged and this combined measure is used throughout. The table also gives the mean original error in inches produced by the prisms for each task.

The results show that subjects obtained the most adaptation on the task on which they were trained, regardless of the order of testing. This averaged 65% of the original error and is significantly greater than the amount of adaptation found on the other tests ($F=5.79$, $df=4,90$; $p=.01$). Nonetheless, the average adaptation found on those tests on which the subjects did not adapt was 44% of the original error. This constitutes a meaningful amount of generalized adaptation, two-thirds of the amount obtained when the subject was trained specifically on a given task.

Table II presents the mean adaptation in inches and percent for each task compared with the position of the task in the order of testing. Overall order of testing was not significant ($F=.75$, $df=2,90$) suggesting no significant decay of adaptation over testing either for compensation or after-effect (a period of roughly 3-4 minutes).

The results support the contention that adaptation to distortion generated

Table I. Amount of Adaptation Produced for Each of the Tasks

Task Tested	Original Error (inches)	Task Used for Adaptation					
		PL		HE		SP	
		Mean Final Error (in.)	% Compen-sation	Mean Final Error (in.)	% Compen-sation	Mean Final Error (in.)	% Compen-sation
Placing (PL)	2.40	0.77	68	1.64	32	0.93	61
Hand-Eye (HE)	2.12	1.27	40	1.01	52	1.43	32
Spearing (SP)	3.69	1.85	50	1.92	48	0.91	75

Table II. The Effect of Order of Testing on Adaptation Measures

Task Tested	Original Error (inches)	Position in Order of Testing					
		1		2		3	
		Mean Final Error (in.)	% Compen-sation	Mean Final Error (in.)	% Compen-sation	Mean Final Error (in.)	% Compen-sation
Placing (PL)	2.40	0.74	69	1.17	51	1.32	45
Hand-Eye (HE)	2.12	1.21	43	1.27	40	1.24	42
Spearing (SP)	3.69	1.83	50	1.16	69	1.70	54

by practice on a specific hand-eye task will transfer to other hand-eye tasks. Visual-motor adaptation, therefore, is probably fairly general and not task specific.

This finding suggests that it would indeed be beneficial to train divers on a specific task under water, since the effect of their training will transfer to other tasks performed under water.

Study III. The Effectiveness of Different Underwater Activities Selected on Theoretical Grounds

Extensive investigations of adaptation to distorted stimulation have been conducted in air and several investigators have proposed theories to explain the modifications in behavior that result; there are a number of good reviews available in the literature.[6-9]

Perhaps the most famous investigator is Richard Held whose theory was evolved to explain his typical result that self-produced movement is essential for adaptive behavior.[5] In Held's experiments the amount of adaptation achieved by subjects who move themselves about is compared to that of individuals who are moved by others through the same visual environment; the active group always achieves some adaptation while the passive group shows very little if any. Held views adaptation as the process of building up associative bonds in the central nervous system. The two factors that become correlated or associated over time are the neural impulses that evoke motor responses (efference) and the sensory inputs (reafference) which are contingent upon these motor commands.[17]

While Held thus emphasizes the new connections between sensory and motor systems, another theorist, Harris[16] proposes that the change occurs in the kinesthetic or tactual sensory system. In his view, the conflict between the incongruous visual and kinesthetic information in the typical prism experiment is resolved in favor of the visual system. The body, or part of the body, eventually is felt to be located where it looks to be. Rock and Harris have in fact shown that the visual information will completely dominate over tactual in the subjects' judgments when the two are in conflict.[4]

A number of other investigators have criticized Held's formulation of lack of control of motivation or attention in the active and passive groups.[18] Howard and Templeton,[8] in an explicit formulation of this point of view, propose that an essential for the adaptation process is "response substitution." When faced with a distorted or incongruent optical input, the subject must first actively inhibit his normal movements and deliberately make allowance for error. The final automatic stage, after new responses have been substituted for the habits through practice, is the true adaptation. Thus, in Howard and Templeton's view, the essential component for response substitution is informational feedback--the subject must be called upon to correct an error and to recalibrate his movements.

In order to assess the validity of these various concepts for underwater

adaptation, a task was selected which subjects could perform in different ways during the adaptation period. The task consisted of placing a chess-piece on a target under water; the target was movable and was positioned in various locations on top of a checkerboard grid. The adaptation period consisted of 20 trials or 20 placements in different positions. Figure 2 shows a team of subjects working at the task.

Procedure

Six different ways of performing the same placing task were devised and subjects assigned randomly to each group or to a control group. The groups are described below:

(1) Active: The subject was handed the chess-piece and asked to place it on the target. The target was then moved

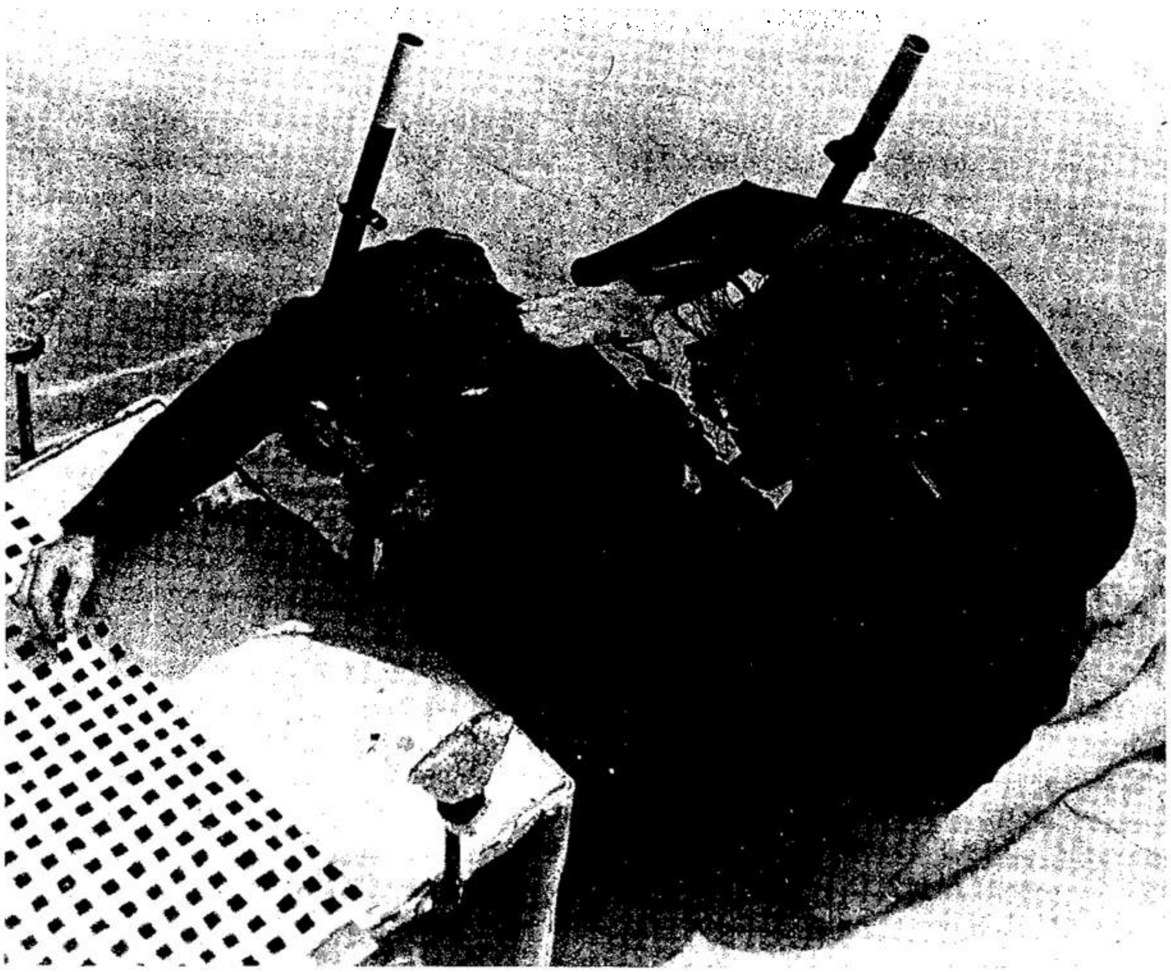

Fig. 2. Team practice in the Placement Task. The subject actually placing the chess-piece is blindfolded; his teammate is signaling where to put it by tapping him on the shoulder.

Thus, the conclusion is that all subjects achieved a small degree of adjustment, 18% on the average, to the underwater distortions. There were no differences in this adjustment which can be ascribed to the type of activity in which they engaged. In fact, simply entering the water and taking the two tests resulted in sufficient underwater activity to achieve this small degree of adaptation.

While our adaptation periods were extremely brief--the 20 trials generally took 3 to 15 minutes--many other investigators[19-26] have achieved significant amounts of adaptation in similar, brief exposure periods in air. However, our goal of near-complete adaptation is more rigorous than that imposed on many theoretical investigations. If a theory states that a specific factor is essential for adaptation, demonstration of even a small amount of adaptation in its absence is, of course, important. Thus, Kalil and Freedman[27] report a 3-degree shift out of a possible 15 degrees; Sekuler and Bauer's[25] highly significant differences amount to 2 and .5 degrees compared to a theoretical 11 degrees; and all of Cohen's[19] differences are less than one inch out of a possible 5.4 inches.

Thus while the 18% adaptation, achieved quite effortlessly in this study, is of interest theoretically, it is of little help in the practical problem of optimizing adaptation for divers. In our next attempt to obtain large amounts of adaptation we therefore abandoned the rigid theoretical positions and selected activities on the basis of general educational principles.

Study IV. The Effectiveness of the Scheduling of Different Underwater Activities in Producing Adaptation

The goal of near-perfect compensation for underwater distortion was not met in the brief exposures tried in the last study. Underwater distortions differ from those commonly investigated in air; the latter almost always are produced by prisms which shift or rotate the entire field of view in the same direction. Compared to the symmetrical distortion produced by water, this uniform shift is both more severe and less complicated. It may well be that it is more difficult to adapt to underwater distortion than to prism distortions. The adaptation period was there-therefore lengthened to 15 minutes. The effectiveness of two other parameters was also investigated: the type of activity and the scheduling of the activity.

Procedure

Type of activity: Subjects either played games under water, heard a lecture and then practiced placing objects under water, or simply swam. The underwater games were a crossword puzzle and a game similar to checkers. This type of activity involves active hand-eye coordinations and presumably good motivation and interest, but no specific knowledge of the underwater distortion.

Another group of subjects was given a lecture and demonstration on the underwater distortions, as follows:

Things that are under water don't look the way they do in air. The reason is that when light-rays travel through water, they are distorted. This does at least three things: (1) It makes things look closer to you than they really are. (2) It makes things that are off to your right look even farther to the right. (3) It makes things on your left look too far to the left.

So, if you were looking at a row of objects in a straight line in front of you (like the black squares), they would look as if they were at the positions of the white squares.

So, if you reach for something underwater, you may miss it because it is actually farther away than it looks and you will probably not reach far enough. And if you reach for something that is off to your right, you will probably reach too far to the right. If you reach for something to your left, you will probably reach too far to the left.

We would like you to look for this distortion in the water, and try to practice to overcome it. A good way to practice is to close your eyes and try placing the piece (which we will give you) on a marker on the board; then open your eyes, see where you actually did place it, and if you missed, do it over and try to improve.

They were then given the same practice period placing objects on the checkerboard grid that was used in the previous study. This activity was repeated in this experiment for two reasons. First, its inclusion allows an evaluation of the increased adaptation time periods since this is the only difference between lecture-practice groups in the two studies. Second, knowledge of results is generally considered to be essential for learning;[28] it is widely used as an educational tool and thus may prove to be effective for adaptation also.

Finally, other subjects were used as a control and simply swam around the pool for the required interval. The pool normally presents a very uniform visual environment to an underwater swimmer; there are no lines, patterns or figures in the field of view. In order to eliminate this homogeneity for some subjects, a second, swimming, control group was added; for these subjects, numerous patterned objects were immersed in the pool to enrich their visual environment.

Scheduling of activity: Educators and learning theorists commonly advocate spaced learning periods, with unrelated intervening activity, as being most conducive to learning.[28] Experimental evidence on the relative effectiveness of "spaced" vs "massed" training or study generally indicate that better results are obtained when the total time to be devoted to the study is spread over a longer interval than when it is expended all at once. An interesting parallel occurs for experienced divers; not only is their total time underwater naturally much greater than that of novices, but also the number of re-entries into the water is likewise greater.

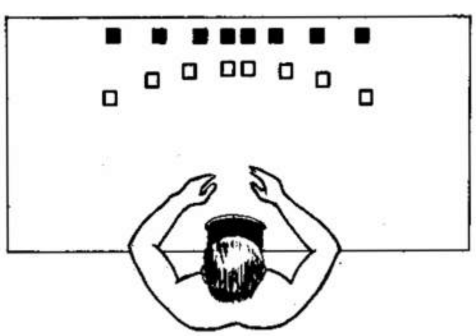

Table V. Analysis of Variance of Results on Test of Hand-Eye Coordination

	Sum of Squares	df	M.S.	F
Total	461.79	299	1.54	
Groups	18.97	5	3.79	2.42*
Individuals within Groups	84.66	54	1.57	
Testing Conditions	297.17	4	74.29	294.18**
Group X Condition Interaction	6.45	20	.32	1.28
Residual	54.55	216	.25	

* 05 level
** 01 level

Table VI. Results of t tests performed on the data on test of hand-eye coordination. Appropriate error terms obtained from analysis of variance.[29]

Type of Comparison Involved	Specific Result	Sign. level
Between groups	Games-Spaced superior to	
	Swim-Spaced	.05
	Swim-Massed	.01
	Games-Massed superior to	
	Swim-Massed	.05
Between Testing Conditions	W_2 more adjustment than W_1	.01
	W_3 more than W_2	.01
	Air after-effect significantly different	
	from 1st air test	.01
	all water tests	.01
Between Testing Conditions for a Single Groups	Air values different from water for every group	.01
Between 2 groups at a single testing condition	On both the third and fourth water tests:	
	Games-Spaced better than	
	Swim-Spaced	.05
	Swim-Massed	.01
	Games-Massed better than	
	Swim-Massed	.01
	Lecture better than	
	Swim-Massed	.05

depth. The summary of the original and final errors in water and in air, Table VII, shows a mean compensation of 45% and a mean after-effect of 35%. Once again, the Games-Spaced Group obtained more adaptation than any of the other groups, as assessed by either their error in water or the size of their after-effect in air. The adjustment over time is shown in Fig. 4 for each of the groups and the analysis of variance is given in Table VIII. Table IX gives the significant t tests; while no different on the first water test, the Games-Spaced Group performed significantly better than all other groups on later water tests.

In general, the results of the two different tests of underwater adjustment

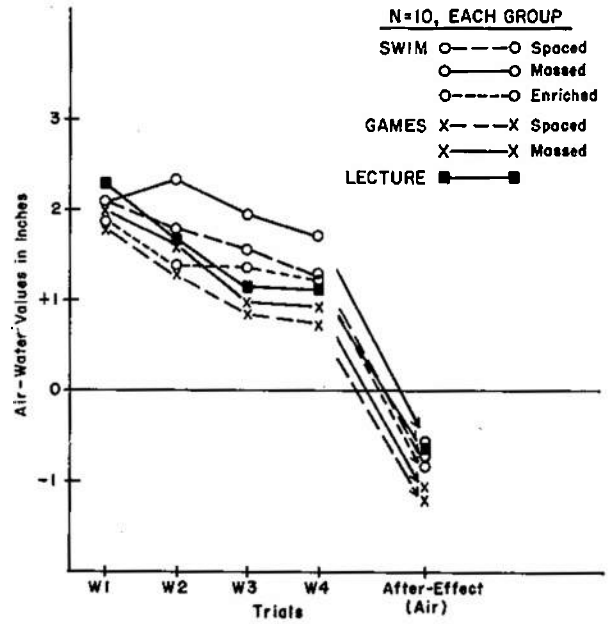

Fig. 4. Mean error for each of groups on successive tests of depth adjustment.

Table VII. Measures on the Test of Position in Depth

Group	Original Error (inches)	Error after 15 min. (in.)	% Comp.	After-Effect (in.)	%
Swim-Massed	1.93	0.98	49.0	-1.02	53.1
Swim-Spaced	2.36	2.12	10.0	-0.47	20.0
Swim Enriched	2.12	1.26	40.7	-0.83	38.9
Lecture	2.68	1.73	35.3	-0.20	7.4
Games-Massed	2.44	1.57	35.5	-0.79	32.2
Games-Spaced	1.85	-0.31	117.0	-1.38	74.5
Mean	2.24	1.22	45.6	-0.79	35.1

Table VIII. Analysis of Variance of Results of Test of Position in Depth

	Sum of Squares	df	M.S.	F
Total	5451.84	299	18.23	
Groups	371.22	5	74.24	2.34
Individuals within Groups	1714.99	54	31.76	
Testing Conditions	2152.37	4	538.09	107.43**
Group X Testing Condition Interaction	131.34	20	6.57	1.09
Residual	1081.93	216	5.01	

** .01 level

Table IX. Results of t tests performed on the data from the Position in Depth Test. Appropriate error terms obtained from analysis of variance[29]

Type of Comparison	Specific Result	Sign. level
Between groups	Games-Spaced superior to	
	Games-Massed	.05
	Lecture	.01
	Swim-Spaced	.01
	Swim-Enriched	.05
Between testing conditions	W_2, W_3, W_4 more adaptation than W_1	.01
	W_4 more than W_3, W_2	.01
	After-effect different from all others	.01
Between testing conditions for a single group	Air values different from water for every group	.01
Between 2 groups at a single condition	On both 3rd and 4th water tests Games-Spaced better than	
	all other	.05
	Swim-Spaced	.01

were in good agreement. There were, however, a few inconsistencies; for example, the poorest performance of any group on the hand-eye table was shown for the Swim-Massed Group; on the position in depth test, the worst was the Swim-Spaced Group. The data for the Games Groups and the Swim-Controls were therefore combined, in order to obtain larger numbers of subjects on which to compare performance. The average values for various combinations are given in Fig. 5.

This analysis shows very similar results for the two tests: playing games under water results in distinctly better performance than does swimming, no matter how it is measured. The scheduling of activity shows a slight superiority for the spaced intervals over the massed; the effectiveness of scheduling differences, however, is much less than the differences due to type of activity.

The results for the Lecture Group, on the water tests, tend to be intermediate between the Games and Swim Groups. They showed very small after-effects on both tests, however. this may indicate that their improvement in the water was a conscious correction, at least in part.

Finally, the general effectiveness of the technique of Games-Spaced is attested to by comparing their adaptation to that of the students in SCUBA class tested previously.[1] Figure 6 presents four consecutive underwater measures on the same Hand-Eye table for these two groups. The Games Group started originally with greater error and ended with less. Moreover, it should be remembered that between the first water test and the last, the SCUBA class had three weeks of underwater experience while the Games Group had a total of 15 minutes of specially designed activity.

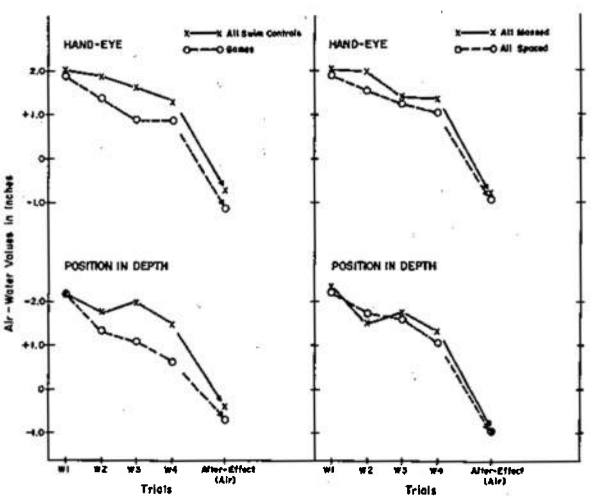

Fig. 5. The two tests of adaptation compared for (1) type of activity (Swim vs. Games) on the left and (2) scheduling of activity (Massed vs. Spaced) on right.

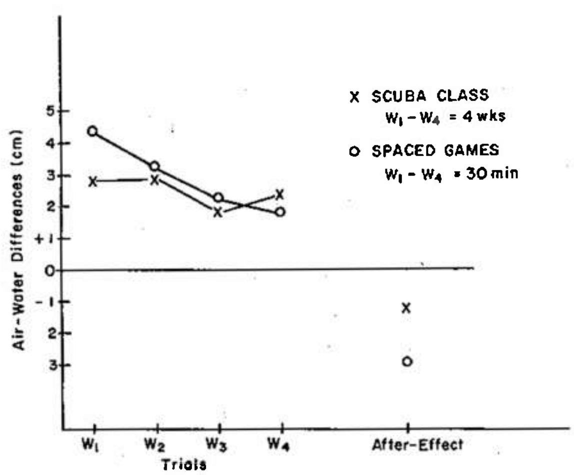

Fig. 6. Comparison of the average error on successive underwater tests for the most successful technique of this experiment, Games-Spaced, and SCUBA students.[1]

GENERAL DISCUSSION

The results of these studies are highly consistent and lead to some interesting conclusions. First, we find that a small amount of adaptation is surprisingly easy to achieve. Control groups, in the various underwater tests, always show a small, but significant amount of adaptation, even though they have had no designated period of underwater activity. This suggests that simply being underwater, engaged in taking the test, provides the opportunity for some adaptation to occur. Even subjects who are blindfolded for their period of underwater activity show some adaptation.

On the other hand, the achievement of completely adapted behavior--the goal for the Navy diver--proved to be extremely difficult. On only one occasion did a group of subjects show adjustive behavior that approximated this ideal; the Games-Spaced Group of Study IV showed 60% and 100% adaptation on the two tests.

One hypothesis capable of handling this apparent conflict is that there are two types of adaptation: one type takes place very quickly but is small in amount, while the second type can be complete but requires extensive experience. Considerable evidence can be amassed to support this hypothesis.

Type I - Visual Adaptation. Two to three minutes under water is apparently enough for some adaptation to occur. This is the approximate time required to give most of our tests under water; it is also about the length of time used in numerous adaptation studies performed in air, studies which obtained some--but by no means sizable--amounts of adaptation. The amount of compensation achieved in this way under water is about 20 percent. This was the average amount for all subjects in Study III, for the Swim controls in Study IV, and for the students in the SCUBA class after their four-week course. It was also approximately the same amount shown by all subjects in a previous experiment[1] when the measure was not hand-eye coordination but was the purely visual perception of size under water.

Two facts from this previous study deserve emphasis in terms of Type I adaptation. First, the test of adaptation had no motor component. It must be a visual phenomenon and may depend upon the different pattern of stimulation or transformation of the optical array across the retina which results from head and eye movements under water as compared with air.[30] Second, the same amount of adaptation to size was achieved by all the subjects, regardless of whether they were qualified Navy divers or whether their underwater experience was zero; totally inexperienced subjects achieved the 20 percent adaptation in only two or three minutes under water.

On the basis of all this evidence, we suggest that Type I adaptation quickly reaches a plateau in terms of both magnitude and time required. That is, individuals may never achieve more adaptation than the 20% that they do in the first few minutes under water, no matter how long they stay. This would explain both why there was no correlation between size perception and underwater experience, even though there was a

large correlation between the latter and hand-eye coordination, and why there has been so much controversy as to whether or not adaptation ever occurs in purely visual perception at all. † The controversy apparently stems from the limited amounts of visual adaptation which are possible; if complete adaptation could occur, as in the case of hand-eye coordination, there would be no controversy.

Type II - Visual-motor adaptation. The second type of adaptation is not purely visual but requires new visual-motor coordinations to be built up over time. It is much more difficult to obtain, but with sufficient time and appropriate experience, can become complete. Such was obviously the case for Kohler's subjects who learned to ski and fence while wearing inverting prisms;[3] complete adjustment was also found in a few of the qualified Navy divers tested previously.[1]

Considerable adaptation was also evident in one of the measures in Study IV for the "Spaced-Games" subjects. Many factors are involved in the activity which produced this adaptation: the subjects were interested in the games and thus motivated to pay attention; the spacing of experience was more effective than massing it; and individuals had to move parts of their body in relation to distorted stimulation from a structured environment. This multiplicity of possible reasons for success makes it impossible for us to differentiate between the theories of Harris[24] and Held[5] in our experiments. Both Held's reafferent stimulation and Harris' changes in felt position will explain the success of the technique equally well.

On the other hand, we can state that conscious control or response substitution, advocated by Howard & Templeton,[8] is not essential. Extensive information about the nature of distortion and controlled practice by their recommended technique did not result in superior adaptation. Indeed, judging from the fact that the after-effects were small for the Lecture Group, this technique may have resulted in too much conscious control and little actual adaptation.

Interestingly, an entirely different line of experimental evidence, the results of depriving neo-natal animals of various visual stimulations, has just recently led to the conclusion that two kinds of adaptation are likely.

Several investigators over the years have shown that rearing animals in the dark or in unpatterned, homogeneous light, markedly interferes with their ability to function normally in a visual environment.[31-33] Yet the empiricist's conclusion that visual experience is essential for seeing has been vigorously attacked. Some studies have failed to reveal deficits,[34] while, in others, it has been suggested that the deficiency was due to neural degeneration.[35]

Myers and McCleary[36] have noted that at least one early investigator, Riesen, reported "visual deficits" based only on tests of visually guided behavior. No tests of visual perception alone were performed. Thus they conclude that the controversy over the effects of visual deprivation stems from the fact that at least two distinct

†See, for example, the discussion in Epstein[7], p. 192-200.

16. Harris, C. S. Perceptual adaptation to inverted, reversed, and displaced vision. Psychol. Rev., 72, 419-444, 1965.

17. Held, Richard. Exposure-history as a factor in maintaining stability of perception and coordination. J. Nerv. Ment. Dis., 32, 26-32, 1961.

18. Weinstein, S., Sersen, E. A., Fisher, L., and Weisinger, M. Is reafference necessary for visual adaptation? Percept. & Mot. Skills, 18, 641-648, 1964.

19. Cohen, M. M. Continuous versus terminal visual feedback in prism after effects. Percept. & Mot. Skills, 24, 1299-1302, 1967.

20. Freedman, S. J. Compensation for auditory rearrangement in hand-ear coordination. Percept. & Mot. Skills, 24, 1207-1210, 1967.

21. Lazar, G., and Van Laer, J. Adaptation to displaced vision after experience with lesser displacements. Percept. & Mot. Skills, 26, 579-582, 1968.

22. Templeton, W. B., Howard, I. P., and Lowman, A. E. Passively generated adaptation to prismatic distortion. Percept. & Mot. Skills, 22, 140-142, 1966.

23. Howard, I. P., Craske, B., and Templeton, W. B. Visuo-motor adaptation to discordant ex-afferent stimulation. J. Exp. Psychol., 70, 189-191, 1965.

24. Harris, C. S. Adaptation to displaced vision: visual, motor or proprioceptive change? Science 140, 812-813, 1963.

25. Sekuler, R. W., and Bauer, J. A. Adaptation to prismatic displacement: Hand position and target location. J. Exp. Psychol., 72, 207-212, 1966.

26. Goldberg, I. A., Taub, E., and Berman, A. J. Decay of prism aftereffect and inter-limb transfer of adaptation. Paper read at Eastern Psychological Association meeting, Boston, April 1967.

27. Kalil, Ronald, and Freedman, S. J. Compensation for auditory rearrangement in the absence of observer movement. Percept. & Mot. Skills, 24, 475-478, 1967.

28. Deese, J., and Hulse, S. H. The Psychology of Learning McGraw-Hill Book Co., 1967. pp 454-461.

29. Cochran, W. G., and Cox, G. M. Experimental Designs 2nd Ed., John Wiley & Sons, Inc., New York, 1957. p. 298.

30. Gibson, J. J. The Senses Considered as Perceptual Systems. Boston: Houghton Mifflin Co. 1966.

31. Riesen, A. H. "Plasticity of behavior: Psychological aspects." In H. F. Harlow and C. N. Woolsey (Eds) Biological and Biochemical Bases of Behavior. Madison: University Wisconsin Press, 1958, Pp 425-450.

32. Hebb, D. O. The Organization of Behavior. New York: Wiley, 1949.

33. Held, R., and Hein, A. Movement-produced stimulation in the development of visually guided behavior. J. Comp. Physiol. & Psychol., 56, 872-876, 1963.

34. Hubel, D. H., and Wiesel, T. N. Receptive fields of cells in triate cortex of very young, visually inexperienced kittens. J. Neurophysiol., 26, 994-1002, 1963.

35. Gibson, J. J. The Perception of the Visual World Boston: Houghton Mifflin. 1950.

36. Meyers, B., and McCleary, R. A. Interocular transfer of a pattern discrimination in pattern deprived cats. J. Comp. Physiol. Psychol., 57, 16-21, 1964.

37. Held, Richard. Dissociation of visual functions by deprivation and rearrangement. Psychol. Forschung, 31, 338-348, 1968.

38. Mikaelian, H., and Held, R. Two types of adaptation to an optically-rotated visual field. Am. J. Psychol., 77, 257-263, 1964.